# Section 6

## ENGINE AND VEHICLE OPERATION ISSUES

## Quick Reference Data

*Heat of Vaporization/ Low Ambient Temperature Starting*

| | Btus/lb |
|---|---|
| Gasoline | 150 |
| Ethanol | 396 |
| Methanol | 506 |

*Existing Vehicle Warranties*

The warranties of most passengers vehicles sold in the United States cover the following fuel concentrations in gasoline:

| | |
|---|---|
| Ethanol | 10% |
| Methanol | 3-5% |
| MTBE | 15% |

*Flexible Fuel Vehicle Mileage/Range*

(1987 Crown Victoria)

| | Miles per gallon | Range (18 gallon tank) |
|---|---|---|
| Gasoline 100 | 16.0-17.4 | 288-313 |
| M25 | 14.3-15.5 | 257-279 |
| M50 | 11.9-12.7 | 214-229 |
| M85 | 9.2-10.2 | 166-184 |
| M100 | 8.5-8.8 | 153-158 |
| E85 | 12.2-12.8 | 220-230 |
| E95 | 11.8-11.9 | 212-214 |

- Fuel economy: Due to higher heating value, straight gasoline provides higher mileage per gallon than any alcohol blend or neat fuel.
- Fuel efficiency: Alcohol fuels are more thermodynamically fuel efficient than gasoline, i.e., alcohols use fewer Btus per mile traveled than gasoline.

## Useful Terms and Definitions (also see Glossary)

- **Enthalpy Requirement:** The additional heat input required by the engine's fuel induction system to achieve the fuel vaporization for smooth operation.
- **Vapor Lock:** Reduced fuel flow to the engine due to increased vapor formation, generally caused by high operating temperatures.

## Key Issues and Implications

### Issues and Implications

*Issue # 1:* *Cold Weather Starts and Warm-up with Neat Alcohol Fuels and High-Level Blends*

**Low ambient temperatures can affect vehicle cold start and warm-up operations when neat and high-level blends of alcohol fuels are used, due to the greater latent heat of vaporization of alcohol fuels.**

*Implications of Cold Starting Problem:*

- Neat alcohols must be blended with other fuels or must have additional equipment installed in the fuel system to facilitate starting.
- For low level alcohol/gasoline blends, cold start and warm-up operations are really not problems since these blends perform essentially the same as unblended gasoline.

*Potential Solutions*

- Numerous options are available to mitigate these problems, ranging from the use of fuel additives to cold start mechanical subsystems.

*Detailed Information:* Refer to pages 6-4 through 6-6.

*Issue # 2:* *Low vapor pressures of alcohol fuels*

**Neat alcohols and high-level alcohol/gasoline blends have characteristically low vapor pressures and flat distillation curves.**

*Implications of Low Vapor Pressure:*

- As the percentage of alcohol in the fuel increases, vehicles could have an increased potential for vapor lock at high ambient temperatures. However, recent test results have not shown this to be the case.

*Potential Solutions:*

- The use of additives and adjustments to fuel flow pressure seems to mitigate any potential problems.

*Detailed Information:* Refer to page 6-9.

*Issue # 3:* *Lower Energy Density of Alcohol Fuels*

**Alcohol fuels contain less energy (Btus) per gallon than gasoline, so as the alcohol content of a fuel increases, the overall driving range for a given vehicle tends to decrease.**

*Implications of Lower Energy Density:*

- Bigger fuel tanks or more frequent fill-up will be required with alcohol fuels. However, this is partially offset by the fact that alcohols are more thermally efficient (i.e., require fewer Btus/mile) than gasoline.

*Detailed Information:* Refer to pages 6-10 through 6-13.

# Section 6
# ENGINE AND VEHICLE OPERATION ISSUES

- Low Ambient Temperature Starting
- High Temperature Performance
- Vehicle Range

## Introduction

Proper operation of a vehicle depends on several factors. In addition to the quality of the delivered vehicle, adherence to scheduled factory maintenance is important in assuring proper operation. **Vehicles designed to run on gasoline are generally warranted to operate on low level ethanol, methanol and ether blends.** The majority of the world's automobile manufacturers warrant their vehicles to operate properly with oxygenated blends according to the limits below:

| | |
|---|---|
| Ethanol | 10% |
| Methanol | 3-5% |
| MTBE | 15%. |

For a complete listing of warranties refer to [1].

Of the alcohol-blending agents available, methanol is the most controversial. Several automobile manufacturers specifically warn the consumer against the use of blends containing methanol in their production vehicles. This is due primarily to concerns about accelerated engine wear, and possible incompatibility with fuel system components.

Vehicles designed to run on higher blends of alcohols than the low levels noted above often exhibit certain driveability problems. Driveability can refer to a fuel's volatility characteristics as well as to any method for judging the overall performance of a particular vehicle. Alcohol-fueled vehicles have been reported to have difficulties with low ambient temperature starting, high temperature performance, and reduced vehicle range. An additional area of concern, fuel system component failures, is examined in Section 7.

## Low Ambient Temperature Starting

Methanol and ethanol have much greater latent heat of vaporization values than gasoline (i.e., they require more heat/gram to vaporize completely). Whereas the value for gasoline is approximately 150 Btu/lb (348.9 kJ/kg), the values for neat alcohols are: methanol - 506 Btu/lb (1176 kJ/kg); and ethanol - 396 Btu/lb (921.1 kJ/kg). [2] Consequently, the warm-up period is extended and acceptable driveability during this phase of engine operation is more difficult to achieve.

The effect is more pronounced as the ambient temperature drops and the proportion of alcohol or alcohol-based ether in a blend increases. The testing methods for cold starting among researchers vary considerably, with the testing temperature and the definition of a successful start being key differences. Recent research has shown that low ambient temperatures affect both low level blends as well as neat alcohol vehicles.

*- Low Level Blends*

Traditionally, the midpoint of a gasoline's ASTM distillation curve has been used as a principal cold-weather driveability control parameter. This method is important because it provides the basis on which gasoline producers can set their specifications to ensure proper driveability performance throughout the vehicle population. Because of non-ideal volatility behavior of alcohol fuels, researchers have defined a new volatility parameter termed "enthalpy requirement". [3] It is defined as the additional heat input required by the engine's fuel induction system to achieve the required degree of fuel vaporization for smooth operation. Initial testing has proven it to be equivalent to the ASTM midpoint parameter for gasoline operation. Whereas the "E100" ASTM midpoint parameter has under-predicted the driveability performance problems with low-level (20% methanol, 10% MTBE) blends, the Standard Enthalpy Requirement Parameter (SER) works equally well with hydrocarbon and oxygenated blends.

**The effect of low temperatures on low-level alcohol blends** is **unclear**. Theoretically, a 10% ethanol blend raises the RVP of a blend by 1 psi. Raising the Reid Vapor Pressure (RVP) in the winter is a typical method of improving cold startability. However, because of the leaning effect of the alcohol, the overall effect will depend on the vehicle fuel system. The leaning effect will be more noticeable in older open-loop carbureted vehicles. Newer vehicles are equipped with more precise fuel metering methods (fuel injection and closed-loop control) which calibrate themselves for slight differences in oxygen content. Fleet results are varied. For more information, refer to [4,5]. Mixtures of 10% ethanol - 90% gasoline are in widespread use in a number of U.S. regions with severe winters, and no major difficulties in cold-winter starting has been reported. However, work at Volkswagen (Figure 6-1), has shown that a blend containing 3.7% oxygen by weight, obtained by mixing 3% methanol and 5% ethanol, produced disruptions in driveability in a carbureted "Polo" sedan which were not acceptable. [6]

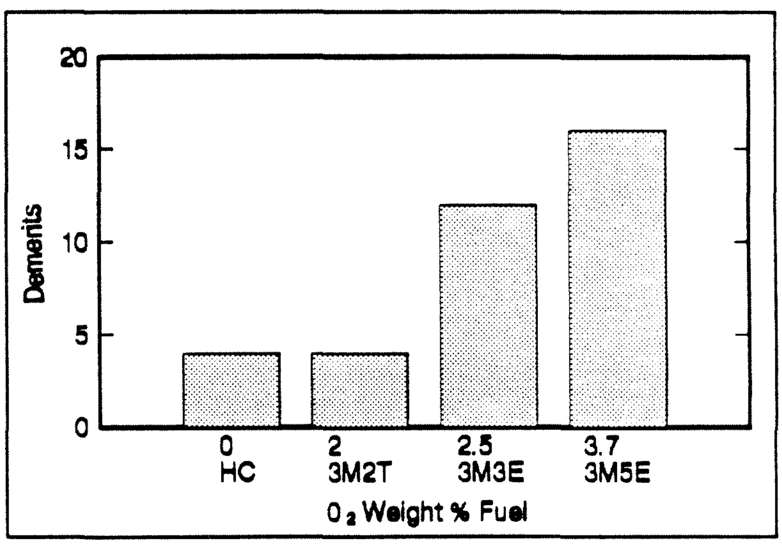


Figure 6-1., Driveability demerits with oxygenated components.

Neste Oy of Finland tested MTBE blends up to 25% down to -25°C. Their temperature data show that the cranking time increases as the MTBE concentration increases and the temperature decreases. The authors conclude based on a demerit rating scale that MTBE does not detract from vehicle performance. [7]

*- High Level Blends*

**Policy Issue #1**

> **The effect of low temperatures on neat and high level blends is very clear: they become difficult to start.** Much effort has been spent on increasing the reliability of cold starting for these fuels.

To aid in starting neat alcohol fueled vehicles at low temperatures, many have experimented with the use of "add-on" technology such as dual fuels, fuel heaters, dissociation of methanol into hydrogen and CO, and dehydration of methanol into dimethyl ether and water. [8,9]

Auto manufacturers such as Ford believe that the additional hardware needed for such systems is not a practical solution [10]. Instead, through the use of cold start engine calibrations they can achieve cold start on M-85 down to -20°F (-29°C). [11]

General Motors has successfully cold started a port fuel injected, 2.5L spark ignition engine down to -20°F (-29C) using 10.5 psi RVP M-85 fuel without heaters or auxiliary fuel injectors. The engine used an exponential decay algorithm for the amount of fuel injected into the cylinders during cranking, along with a high current ignition system. [12]

The cold start limits of neat (i.e., 100% pure) alcohols compared to seasonal gasoline blends are shown below in Figure 6-2. [13] As mentioned before, a fuel's ability to start at low temperatures depends on its RVP. RVP is normally measured at a temperature of 38°C, and at that temperature a typical winter blend has an RVP of .9 bar. Figure 6-2 shows the reduction of vapor pressure with temperature. At a given vapor pressure, methanol has a lower temperature threshold than ethanol.

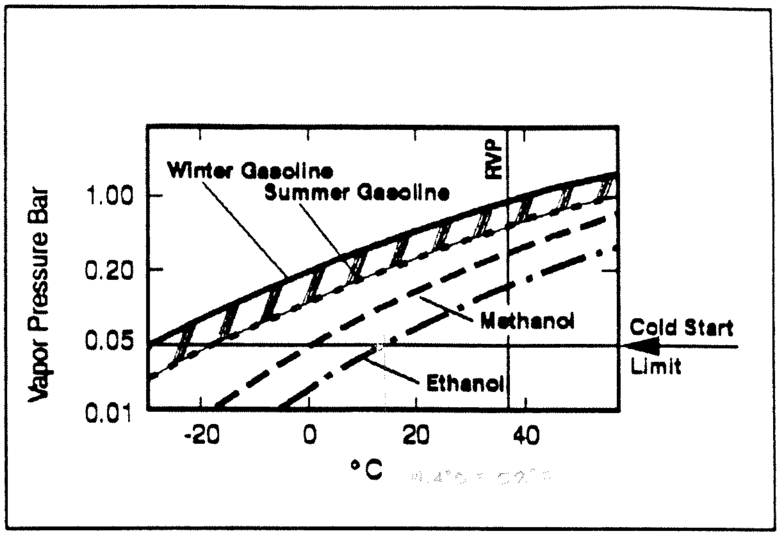


Figure 6-2., Vapor Pressure of ethanol, methanol, and gasoline dependence on temperature.

The addition of front-end volatility enhancing agents improves cold starting of high level alcohol blends. Additives tested by researchers include gasoline, butane, isopentane, and dimethyl-ether. Volkswagen found that the addition of 8% by volume of isopentane extended the cold start limit of methanol from +10°C to approximately -20°C, as shown in Figure 6-3. [14]

Figure 6-4 [15] below shows how gasoline, butane, isopentane and dimethyl-ether affect the limit temperature of cold startability. The additives are arranged in the order of their ability to extend the cold start limit. The L, M, and H following the methanol content designate low, medium, and high RVP regular gasoline blends. For example, RGM85M refers to a M85/15% regular gasoline blend of medium volatility. An isopentane M-90 blend was found to extend the limit to -32°C. The cold temperature limits decrease significantly with small additions of the above mentioned additives.

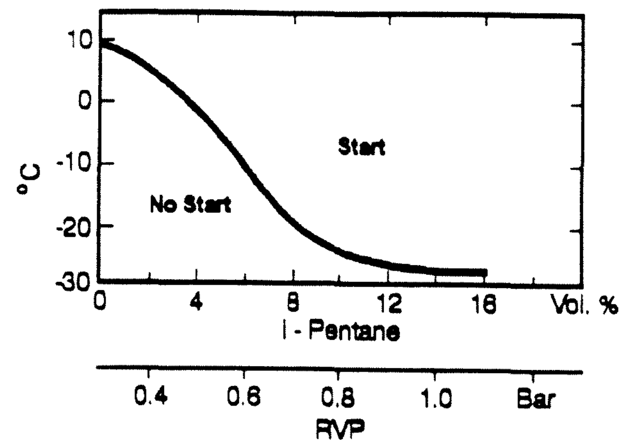


Figure 6-3., Cold start performance of methanol/i-pentane blends.

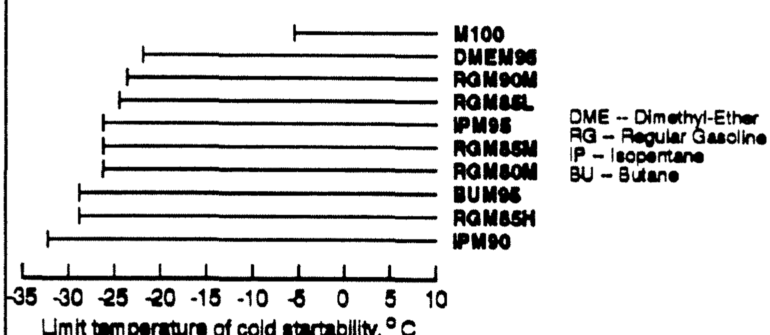


Figure 6-4., Effect of additives to methanol on cold start temperature limits.

## High Temperature Performance

When gasoline as well as alcohol blends in a vehicle are exposed to high operating temperatures, vapor tends to form in fuel pumps, fuel rails, lines and carburetors. If too much vapor is formed, a decrease in fuel flow can occur to the engine resulting in symptoms of vapor lock. These include stalling, hesitation, loss of power or complete stoppage followed by difficult restarting. Vapor lock can become a real problem as temperatures rise above the boiling points of fuels upon shutdown of an engine, making restarting very difficult. Proper engine design techniques can help alleviate the problem. New fuel injection systems operate at higher pressures to minimize vapor formation during the pressure drops that occur during fast acceleration. Because of their lower heating values, alcohol fuels require fuel injection systems to deliver an increased amount of fuel per unit time, requiring even higher pressures than gasoline-fueled vehicles. [16]

- *Low Level Blends*

**High temperature performance of unmodified present day vehicles on low-level alcohol blends is generally not a problem.** As previously mentioned, the majority of the world's auto manufacturers state in their 1990 car warranties that the use of low-level alcohol blends is acceptable. However, they caution that if driveability problems are encountered, one should discontinue use. Because of the RVP increase associated with 10% ethanol blends, high temperature operation of vehicles can increase the possibility of vapor lock conditions. Research has shown varying degrees of severity, dictated by vehicle fuel control technology. [17,18] Because closed-loop system technology allows for slight variations in fuel air ratio, little or no negative driveability effects are encountered due to leaning caused by the ethanol. Older open-loop, carbureted vehicles experience more driveability problems associated with ethanol leaning effects.

Work at Toyota has shown that the Fuel Evaporative Vapor Index (FEVI), used to predict a fuel's tendency to vapor lock, fails to predict this possible deterioration in driveability when using low-level methanol blends. The reason for this discrepancy is that, compared to gasoline, the volatility of blended fuels increases at a greater rate as the temperature approaches the actual operating temperatures of 100°C. Figure 6-5 [19] shows that hot start cranking time increases as the percentage of methanol increases.

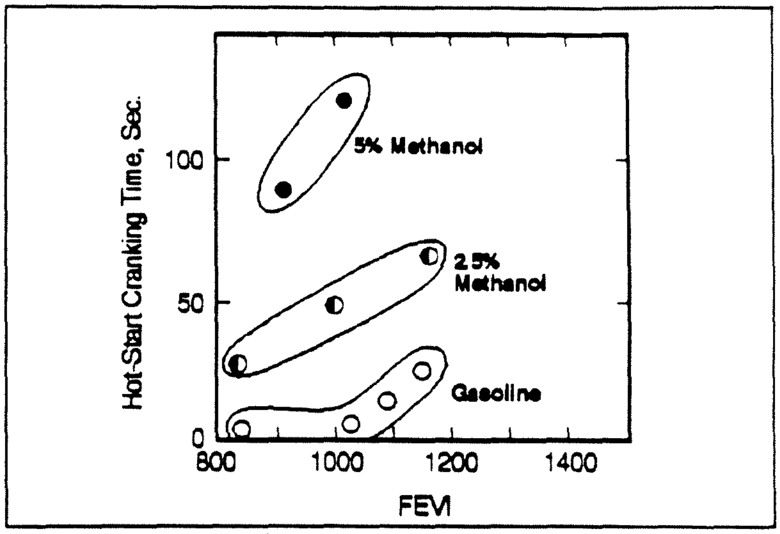


Figure 6-5., Relationship between cranking time and FEVI for low level methanol blends.

Compared to methanol, ethanol should produce less of a negative effect because of its lower volatility. Toyota's warranty, typical of most major manufacturers including the three largest U.S. automakers, states: "If driveability problems are encountered (poor hot starting, vaporizing, engine knock, etc.), discontinue use". [20] Clearly the effect of low-level alcohol blends during high operating conditions depends on the specific fuel system and fuel being used.

*- High Level Blends*

**Policy Issue #2**

**High operating temperatures increase the possibility of vapor lock as the percentage of alcohol increases. This is due to the volatility characteristics, low RVP, and flat distillation curves (see Section 4, Figure 4-3) of neat methanol and ethanol.**

While the first generation Bank of America carbureted vehicles had difficulties with vapor lock [21], the newer fuel injected dedicated neat alcohol fuel vehicles and flexible fuel vehicles or FFVs do not seem to exhibit these problems. The California Air Resources Board (CARB) describes driveability and performance to be generally very good and excellent for their dedicated alcohol fuel VW, Toyota, Ford FFV* Crown Victorias, and GM VFV* Corsicas. These vehicles generally operate on M85 blends containing a 40% aromatic-based gasoline. [22] The high level of aromatics is added to increase the RVP to aid in cold weather starting. Seasonally, gasoline blenders change the mixture of components in their fuels. Winter gasoline generally has more volatile additives to increase the ease of cold weather starting. In fall and spring, the arrival of unseasonally warm weather can adversely affect the performance of cold weather blends. High operating temperatures may lead to vapor lock in the engines running on a cold weather blend. [23] Similarly, high-alcohol blends require the use of very volatile additives to provide the volatility needed for cold weather operation. These blends are equally susceptible to vapor lock during unseasonably warm weather.

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*Ford Motor Company has adopted the term "Flexible Fuel Vehicle" or FFV for its prototype multi-fuel vehicles, while General Motors uses the term "Variable Fuel Vehicle" or VFV. We will adopt the most common usage and refer to all vehicles designed to operate on gasoline, alcohols, and gasoline/alcohol blends as flexible fuel vehicles or FFVs.

## Vehicle Range

**Policy Issue #3**

**The effect of alcohol content on a vehicle's range is well known. Alcohols have less energy content/unit volume than gasoline. As the alcohol content of a fuel increases, the overall range for a given vehicle tends to decrease.**

Because ethanol has a higher heating value and greater air/fuel requirement than methanol, its overall vehicle range if tested in the same vehicle would fall between that of gasoline and methanol. The decrease in overall vehicle range when using methanol is clearly shown in Figure 6-6 below. [24] The vehicle is a Ford Flexible Fuel Vehicle (FFV) Crown Victoria which can operate on any blend methanol/gasoline or ethanol/gasoline blend.

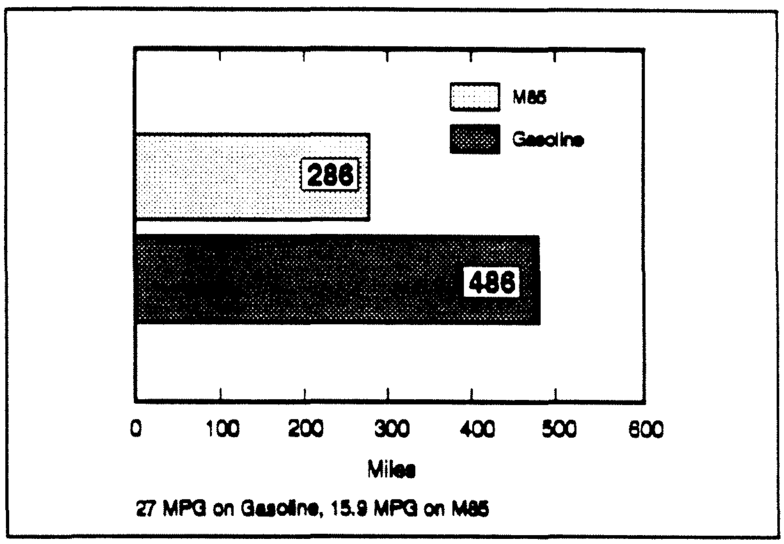


Figure 6-6., FFV vehicle range on M-85 and gasoline.

Differences in a particular vehicle's range are primarily dictated by the fuel economy of the vehicle/fuel combination. Fuel efficiency is an additional energy-based parameter used to describe a particular fuel.

***Fuel economy*** is measured in units of distance per unit volume of fuel, either miles per gallon or kilometers per liter (or gallon). A recent study conducted by the State of Colorado describes their oxygenated fuels program in which 1.8 million vehicles travelled over 4.8 billion miles. The state found a decrease of 1-3% in fuel economy for the newest closed-loop technology vehicles operating on a 10% ethanol blend. This slight decrease is due primarily to the 3% lower Btu/gallon value of a 10% ethanol blend. [25,26] The California Air Resources Board or CARB has been periodically testing methanol fueled prototypes since 1980. [27] In Brazil the majority of the fleet operates on neat ethanol, although the Brazilian consumer has the option of purchasing 22% ethanol/ 78% gasoline vehicles as well. [28] Table 6-1 is a compilation of fuel economy figures from CARB and the Brazilian Motor Vehicles Manufacturers Association. [29,30]

**Table 6-1**

| Vehicle | Fuel | Fuel Econ. (MPG) | Gasoline Equiv. MPG |
|---|---|---|---|
| | | *CARB DEDICATED* | |
| 81 VW | M85 | 12.8-16.0 | 22.6-28.3 |
| 81 VW | M85 | 12.0-15.1 | 21.2-26.7 |
| 83 ESCORT | M85 | 12.6-13.7 | 22.3-24.2 |
| 83 ESCORT | M85 | 13.6-14.7 | 24.0-26.0 |
| 83 ESCORT | M85 | 13.6-17.0 | 24.0-30.0 |
| 83 ESCORT | M85 | 13.1-17.2 | 23.1-30.4 |
| 85 CAMRY | M85 | 15.0-17.2 | 26.5-30.4 |
| 86 CAMRY | M85 | 16.0-16.2 | 28.3-28.6 |
| 86 CARINA | M85 | 18.1-20.5 | 32.0-36.2 |
| 87 CROWN VICTORIA | M85 | 9.7-10.0 | 17.1-17.7 |
| 88 CORSICA | M85 | 11.4-12.0 | 20.1-21.2 |

*U.S. CARB MULTIFUEL*

| | | | |
|---|---|---|---|
| 87 FFV CROWN VICTORIA | GAS | 16.0-17.4 | --- |
| | M25 | 14.3-15.5 | 16.4-17.8 |
| | M50 | 11.9-12.7 | 16.0-17.1 |
| | M85 | 9.2-10.2 | 16.2-18.0 |
| | M100 | 8.5- 8.8 | 17.4-18.0 |
| | E85 | 12.2-12.8 | 17.3-18.1 |
| | E95 | 11.8-11.9 | 7.5-17.7 |
| 88 VFV CORSICA | GAS | 19.8-22.3 | --- |
| | M25 | 17.8-18.4 | 20.4-21.1 |
| | M50 | 15.2-16.4 | 20.4-22.0 |
| | M85 | 11.6-12.5 | 20.5-22.1 |
| | M100 | 11.0 | 22.5 |

| *BRAZIL* | | CITY | HGWY | GAS. EQUIV. CITY | GAS. EQUIV. HGWY |
|---|---|---|---|---|---|
| 86 FIAT PREM. | E95 | 20.0 | 29.8 | 29.7 | 44.3 |
| | GAS | 27.7 | 40.4 | | |
| 86 ESCORT | E95 | 23.3 | 32.4 | 34.7 | 48.2 |
| | GAS | 29.4 | 44.0 | | |
| 86 CHEVETTE | E95 | 21.1 | 27.3 | 31.4 | 40.6 |
| | GAS | 25.8 | 33.8 | | |
| 86 VW GOLF | E95 | 20.9 | 28.7 | 31.1 | 42.7 |
| | GAS | 27.0 | 35.5 | | |

* CARB mileage figures collected under FTP test procedure.

Due to the wide a variety of factors which affect fuel economy, comparisons between vehicle types do not give accurate conclusions about a fuel's ability to provide greater mileage. However, in a FFV or VFV, straight gasoline with its higher heating value, provides higher mileage per gallon than any alcohol blends or neat fuels. Moreover, the CARB figures for the FFV Crown Victoria show ethanol to provide more miles per gallon than methanol, illustrating its higher Btu/gallon value.

The flexible fuel vehicle is clearly a compromise, designed to operate on the gasoline which is available everywhere in the United States and to operate reasonably well on alcohol fuels and blends. Vehicles designed specifically to operate on ethanol or methanol would not have to make these design compromises. They would take full advantage of the higher power and greater efficiency of alcohol fuels, would use the higher compression ratios, and other design decisions that would increase the mileage and performance of alcohol fuels above shown in Table 6-1.

***Fuel efficiency*** is measured thermally instead of volumetrically. Alcohol fuels are more thermodynamically fuel efficient than gasoline. This comparison is made in units of energy per unit mile travelled (typically Btus/mile). [31] Comparing the average values of the FFV Crown Victoria on gasoline, methanol and ethanol in Table 6-2, we see the higher efficiency of both methanol and ethanol over gasoline.

**Table 6-2**

| Fuel | MPG | Heating Value Btu/Gal) | Btu Mile | Improvement |
|---|---|---|---|---|
| Gasoline | 16.7 | 116,000 | 6945 | ---- |
| Methanol | 8.7 | 56,800 | 6528 | 6.0% |
| Ethanol | 11.8 | 76,000 | 6440 | 7.2% |

The example is meant for illustrative purposes, to explain the concept of comparing the efficiency of fuels using the energy required per unit mile. Actual experiments by General Motors have shown alcohol to be slightly more fuel efficient than gasoline (for more information refer to). [32] Results can vary considerably depending on the heating values used and differences in volatility enhancement additives.

## ENDNOTES

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